Research Grants for PhD Students from the China Scholarship Council

Title: **Vibration Synthesis of Parallel Robots through Analytical Bearings Stiffness Modeling with a Guaranteed Given Accuracy for Machining Application.**

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**State-of-art:**

The parallel robots are now gradually being implemented to carry out various applications in various fields such as medical, flight simulation and high-speed machining. To make the accuracy of these machines compatible with these applications, it is necessary to model, identify and compensate all the effects that degrade this precision. These effects may be caused by:

- Errors in the geometry tolerances of the structure associated with machining and assembly errors of the various constituting bodies,

- Elastic deformations of their structure under the effect of the weight of the load on the one hand and their own elements on the other hand,

- Structural vibrations (bodies and joints) as a result of inertia forces applied on their parts and on the load during high-speed trajectory or at the interaction between own modes of the structure and dynamic excitation at the tool interface.

- Errors due to the lack of knowledge of inertial parameters of elements of the mechanical structure, which are implemented in a dynamic control.
The work recently completed on this set of themes within the Processes and Systems of Manufacture Team showed the relevance of an elasto-geometrical and elasto-dynamic modeling and its calibration. The analytical models thus defined make it possible to calculate the static deformation of the structure, under the effect of the weight of the load on the one hand, and of the weight of the elements of the structure on the other hand and let calculate in real-time the modal cartography and vibratory deformations of parallel structures due to the effects of inertia forces applied on their parts and on the load in high-speed operating conditions, or machining cycle.

Next work is a further development of the vibration synthesis on parallel manipulators to compensate for errors in positioning of the tool. There are many factors including the mass content of the actuators, the bearing flexibilities, play and hysteresis problems at their joint components that contribute significantly to the overall dynamic structural behaviour of the system. The elasto-dynamic model accuracy should be increased to predict the effect of these factors on the positioning deformations of the tool. In a first step, we will focus on the bearing flexibilities of the passive joints. In literature, the stiffness of the robot’s joints is classically described using elastic elements with their associated stiffness matrix. For sake of simplicity, the associated stiffness matrix is constant and diagonal, described only by the axial and radial translational stiffnesses and the axial and radial rotational stiffnesses. The idea here is the calculation of the stiffness matrix of angular contact ball bearings joint by using the analytical approach developed in:


This formulation should be more accurate for setting up static and dynamic problems and could facilitate the work of designers who want to exploit the nonlinear load displacement relationships. The stiffness matrices are obtained from calculations which are simple enough to be used directly for calibration procedure with very few parameters to identify (bearing preload for example). As the resulting stiffness matrix and its associated tangent matrix differ from each other in only a multiplicative factor, it is very easy to solve problems expressed from this formulation either in static or vibration analysis.

To do so, we must analyse the performance of the bearing model, taking into account off-diagonal terms and non-linear load displacement behaviour in the elasto-static and elasto-dynamic models of a planar 3RRR parallel robot already established through the ADAMS software. The validity of the identified parameters will be also verified by a comparison of the measured vibration behaviour through a modal analysis on the 3RRR parallel robot available at the laboratory with the behaviour of the proposed model.

**Study required:**

1) Literature review on elastic and dynamic identification of parallel robots. Will be discussed during this literature review, aspects of modelling and identification of the stiffness of angular ball bearing joints.

2) Increase accuracy of the elasto-static and elasto-dynamic models of the planar 3RRR robot obtained through the ADAMS Software.
3) Sensitivity study of the implemented parameters of the analytical stiffness matrix of the angular ball bearing joint in the static accuracy and structural vibrations of the 3RRR robot.

4) Experimental validation of the methods on the planar 3RRR parallel robot available at the laboratory:
   - Elasto-geometric calibration,
   - Dynamic calibration,
   - Verification of the elasto-dynamic modelling by identifying the modal cartography of the structures by experimental modal analysis (Dynamic Shaker - Operating Deflection Shape),

5) Transfer of results and validation of methods in an industrial context.

**Skills and knowledge required:**
- Modelling, Analysis, Simulation and Optimization knowledge
- Robotic (Serials and Parallel Structure) knowledge
- Modeling skills (MATLAB, CATIA, ADAMS)
- Vibrations analysis
- Experimental Modal Analysis